EO/US
PCT/GB00/02780

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION OF ELECTION

(PCT Rule 61.2)

To:

Commissioner
US Department of Commerce
United States Patent and Trademark
Office, PCT
2011 South Clark Place Room
CP2/5C24
Arlington, VA 22202
ETATS-UNIS D'AMERIQUE

in its capacity as elected Office

Date of mailing: 01 February 2001 (01.02.01)	
International application No.: PCT/GB00/02780	Applicant's or agent's file reference: A25819 WO
International filing date: 19 July 2000 (19.07.00)	Priority date: 23 July 1999 (23.07.99)
Applicant: COTTER, David	

1. The designated Office is hereby notified of its election made:

[X] in the demand filed with the International preliminary Examining Authority on:

10 October 2000 (10.10.00)

[ ] in a notice effecting later election filed with the International Bureau on:

2. The election [X] was

[ ] was not

made before the expiration of 19 months from the priority date or, where Rule 32 applies, within the time limit under Rule 32.2(b).

The International Bureau of WIPO **34, chemin des Colombettes** **1211 Geneva 20, Switzerland** Facsimile No.: (41-22) 740.14.35	Authorized officer: J. Zahra Telephone No.: (41-22) 338.83.38

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PATENT COOPERATION TREATY

PCT

REC'D 12 OCT 2001

WIPO PCT

INTERNATIONAL PRELIMINARY EXAMINATION REPORT

(PCT Article 36 and Rule 70)

Applicant's or agent's file reference A25819 WO	**FOR FURTHER ACTION** See Notification of Transmittal of International Preliminary Examination Report (Form PCT/IPEA/416)	
International application No. PCT/GB00/02780	International filing date *(day/month/year)* 19/07/2000	Priority date *(day/month/year)* 23/07/1999
International Patent Classification (IPC) or national classification and IPC H04B10/17		
Applicant BRITISH TELECOMMUNICATIONS P.L.C.et al.		

1. This international preliminary examination report has been prepared by this International Preliminary Examining Authority and is transmitted to the applicant according to Article 36.

2. This REPORT consists of a total of 5 sheets, including this cover sheet.

   ☒ This report is also accompanied by ANNEXES, i.e. sheets of the description, claims and/or drawings which have been amended and are the basis for this report and/or sheets containing rectifications made before this Authority (see Rule 70.16 and Section 607 of the Administrative Instructions under the PCT).

   These annexes consist of a total of 6 sheets.

3. This report contains indications relating to the following items:

   I ☒ Basis of the report
   II ☐ Priority
   III ☐ Non-establishment of opinion with regard to novelty, inventive step and industrial applicability
   IV ☐ Lack of unity of invention
   V ☒ Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations suporting such statement
   VI ☐ Certain documents cited
   VII ☒ Certain defects in the international application
   VIII ☒ Certain observations on the international application

Date of submission of the demand 10/10/2000	Date of completion of this report 10.10.2001
Name and mailing address of the international preliminary examining authority: European Patent Office D-80298 Munich Tel. +49 89 2399 - 0 Tx: 523656 epmu d Fax: +49 89 2399 - 4465	Authorized officer Phillips, S Telephone No. +49 89 2399 8674

Form PCT/IPEA/409 (cover sheet) (January 1994)

I. Basis of the report

1. With regard to the **elements** of the international application *(Replacement sheets which have been furnished to the receiving Office in response to an invitation under Article 14 are referred to in this report as "originally filed" and are not annexed to this report since they do not contain amendments (Rules 70.16 and 70.17))*:

   Description, pages:

1,5-7	as originally filed	
2-4,4a	with telefax of	22/05/2001

   Claims, No.:

1-8	with telefax of	22/05/2001

   Drawings, sheets:

1/4-4/4	as originally filed

2. With regard to the **language**, all the elements marked above were available or furnished to this Authority in the language in which the international application was filed, unless otherwise indicated under this item.

   These elements were available or furnished to this Authority in the following language: , which is:

   - ☐ the language of a translation furnished for the purposes of the international search (under Rule 23.1(b)).
   - ☐ the language of publication of the international application (under Rule 48.3(b)).
   - ☐ the language of a translation furnished for the purposes of international preliminary examination (under Rule 55.2 and/or 55.3).

3. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international preliminary examination was carried out on the basis of the sequence listing:

   - ☐ contained in the international application in written form.
   - ☐ filed together with the international application in computer readable form.
   - ☐ furnished subsequently to this Authority in written form.
   - ☐ furnished subsequently to this Authority in computer readable form.
   - ☐ The statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
   - ☐ The statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished.

4. The amendments have resulted in the cancellation of:

- ☐ the description, pages:
- ☐ the claims, Nos.:
- ☐ the drawings, sheets:

5. ☐ This report has been established as if (some of) the amendments had not been made, since they have been considered to go beyond the disclosure as filed (Rule 70.2(c)):

   (Any replacement sheet containing such amendments must be referred to under item 1 and annexed to this report.)

6. Additional observations, if necessary:

V. Reasoned statement under Article 35(2) with regard to novelty, inventive step or industrial applicability; citations and explanations supporting such statement

1. Statement

Novelty (N)	Yes:	Claims	1-8
	No:	Claims	
Inventive step (IS)	Yes:	Claims	1-8
	No:	Claims	
Industrial applicability (IA)	Yes:	Claims	1-8
	No:	Claims	

2. Citations and explanations
   see separate sheet

VII. Certain defects in the international application

The following defects in the form or contents of the international application have been noted:
see separate sheet

VIII. Certain observations on the international application

The following observations on the clarity of the claims, description, and drawings or on the question whether the claims are fully supported by the description, are made:
see separate sheet

Reference is made to the following document:

D1: Cotter D et al: 'Asynchronous Digital Optical Regeneration and Networks' Journal of Lightwave Technology, US, IEEE. New York, vol. 16, no. 12, pages 2068-2080

Section V

1. The application relates to an optical regenerator and method (**claims 1 and 4**).

2. Document D1 is regarded as being the closest prior art to the subject matter of **claims 1 and 4** and discloses in Figure 10 an asynchronous digital optical regenerator in which an optical data stream is gated with delayed versions of a local optical pulse source,

   from which the subject-matter of claims 1 and 4 differs in that the incoming optical data stream is divided into a plurality of further optical data streams each having a lower bit rate than the bit rate of the incoming optical data stream, and in that each of the further optical data streams is passed to an input of an optical gate means having an optical clock stream fed to its other input at the frequency of the bit rate of each further optical data stream or a multiple thereof.

   The subject-matter of **claims 1 and 4** is therefore novel (Article 33(2) PCT).

3. Problem: How to realize an optical regenerator which can function at higher data rates than prior art designs, in which functioning is limited by recovery time of an optical gate.

4. Solution: The feature which is new with respect to the available prior art is that the incoming optical data stream is divided into a plurality of further optical data streams each having a lower bit rate than the bit rate of the incoming optical data stream, and in that each of the further optical data streams is passed to an input of an optical gate means having an optical clock stream fed to its other input at the frequency of the bit rate of each further optical data stream or a multiple thereof. None of the available prior art documents provide any hint to do this and hence

the particular solution is non-obvious and considered to be inventive (Article 33(3) PCT).

5. The dependent claims add further features to the independent claims and thus also relate to novel and inventive subject matter and hence meet the requirements of Article 33(2) and (3) PCT.

Section VII

1. Contrary to the requirements of Rule 5.1(a)(ii) PCT, the relevant background art disclosed in document D1 is not mentioned in the description, nor is this document identified therein.

2. Independent **claims 1 and 4** are not in the two part form in accordance with Rule 6.3(b) PCT.

3. In the description of the present application (page 3 line 21), the document should have been identified by its relevant publication number.

Section VIII

1. The following claim is unclear in the sense of Article 6 PCT for the reason given below:

   Claim 4: There is no antecedent basis for "the received optical data signal" (last line).

known as the gate window. The state of the gate is unchanged if a binary digit '0' occurs in the optical control signal. The state of the non-linear element then determines whether a given pulse in the optical clock train at the input to the gate is passed on to the output from the gate. In this way, the bit pattern in the input data stream is imposed on the optical clock train and output to form a regenerated optical data stream. However, while experiments reported in Kelly A E et al, Electronics Letters, (in press, July 1999) have shown that semiconductor based all-optical regenerators can function at bit rates as high as 80Gbit/s it has been found that they are unable to perform satisfactorily at still higher bit rates, since then in general the bit period is very much less than the recovery time of the optical gate, so that the regenerated signals contain patterning effects which lead to bit errors.

According to a first aspect of the present invention, there is provided an optical regenerator including: (a) a data division stage arranged to receive an incoming optical data stream having a bit rate and to divide the incoming optical data stream into a plurality of further optical data streams each having a lower bit rate than the bit rate of the incoming data stream; and, (b) a regeneration stage, including a plurality of optical gate means each arranged to receive a respective one of the further data streams at its control input and to receive at another input an optical clock stream at the frequency of the bit rate of the further data streams or a multiple thereof, wherein the outputs of the gate means are connected in common to an optical output (5) of the regenerator and arranged to provide a bit interleaved regenerated optical data stream at the said output.

The present invention provides an all-optical generator that is able to function at far higher bit rates than existing designs. For example, using current technologies, an all-optical regenerator functioning at 160Gbit/s can be constructed. The present inventors have realised that although the functioning of an optical regenerator is limited by the recovery time of the optical gate, the impact of that recovery time is different for a regular clock signal, as opposed to a signal comprising a random data sequence. Accordingly, a gate that may be able to function effectively as a regenerator for data signals only up to 80Gbit/s can nonetheless function as a demultiplexer for data signals at twice that bit rate. The regenerator of the present invention takes advantage of this difference to provide a system capable of operating at far higher bit rates. This is achieved by first dividing down the higher bit rate data

stream into a number of parallel data streams at a lower bit rate and then applying these different divided data streams at the lower bit rate as control signals to a number of gates, each of which is receiving a clock signal at the frequency of the lower bit rate or a multiple thereof at its input. Then when the outputs of the different gates are interleaved, the result is a regenerated data stream at the higher bit rate.

Preferably the data division stage comprises a plurality of gate means each arranged to receive the data stream at a respective driving input and a clock stream at the frequency of the lower bit rate at a respective control input and delay means arranged to impose a different respective delay on the clock signal at the frequency of the lower bit rate relative to the higher bit rate data signal for each of the respective gate means.

The all-optical regenerator may be arranged to function in a bit synchronous network, in which case it may receive clock signals from local clock sources that are synchronised to a bit-level clock. In such a system, each of the gate means may comprise a single optical gate, for example using a TOAD (teraHertz optical asymmetrical demultiplexer) structure.

Alternatively, the optical regenerator may be used in a network which functions asynchronously at the bit-level. In this case, the optical regenerator may incorporate the regenerator structures described and claimed in the present applicant's co-pending application PCT/GB99/01159. In this case, each of the gate means in the regeneration stage may comprise an array of optical gates, and delay means arranged to impose a different respective delay in the clock stream relative to the data stream at each of the array of optical gates, and an optical switch connected to the outputs of all of the array of optical gates, and arranged selectively to output the optical data stream from one of the gates of the array. Alternatively, as described in our co-pending application, a single gate means may be used in conjunction with means to shift the phase of the incoming packet to match that of a local free-running optical clock source.

According to a second aspect of the present invention, there is provided a.
A method of regenerating an optical data signal including:

(a) dividing an incoming optical data signal at a bit rate into a plurality of further data streams each having a lower bit rate than the bit rate of the received optical signal;

(b) gating under the control of the plurality of further data streams a clock signal at the frequency of the bit rate of the further signals or a multiple thereof; and

interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the bit rate of the received optical data signal.

Systems embodying the present invention will now be described in further detail by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic of an optical regenerator embodying the invention;

Figure 2 is a diagram showing an optical gate suitable for use in the regenerator in Figure 1;

Figure 3 is a diagram showing a gate array for use in the regenerating stage of an asynchronous optical regenerator embodying the invention.

An optical regenerator comprises an optical data division stage 1 and an optical regeneration stage 2. An optical time division multiplexed (OTDM) data stream at a high bit rate, in this example 160Gbit/s, is received at an optical input 3 of the data division stage 1. Divided data streams at a lower bit rate, in this example 80Gbit/s are passed from optical outputs 4a, 4b of the data division stage 1 into the optical regeneration stage 2. The data streams are used to gate an optical clock signal at the frequency of the lower bit rate or a multiple thereof, in this example 80 GHz, so as to produce at the optical output 5 of the regeneration stage 2 a regenerated high bit-rate optical data stream.

In a regenerator for use with a synchronous data stream, the data division and regeneration stages require in total 2n optical gates where n is the ratio between the bit rate of the optical data stream and the lower bit rate of the divided data streams input to the regeneration stage 2. In the present example, n = 2 and there are two optical gates in the division stage 1 and a further two optical gates in the regeneration stage 2. As shown in Figure 1, each of the two gates in the division stage 1 is connected in common to the optical input 3 and is driven by the 160Gbit/s optical pulse stream. An optical clock signal at the lower bit rate of 80GHz is applied

to each of the optical gates 6, 7. An optical delay 8 is included between the optical feeds to the gates 6, 7. The magnitude of the optical delay is said to be equal to the

CLAIMS

1. An optical regenerator including:

(a) a data division stage (1) arranged to receive an incoming optical data stream having a bit rate and to divide the incoming optical data stream into a plurality of further optical data streams each having a lower bit rate than the bit rate of the incoming data stream; and

(b) a regeneration stage (2), including a plurality of optical gate means (9,10) each arranged to receive a respective one of the further data streams at its control input and to receive at another input an optical clock stream at the frequency of the bit rate of the further data streams or a multiple thereof, wherein the outputs of the gate means are connected in common to an optical output (5) of the regenerator and arranged to provide a bit-interleaved regenerated optical data stream at the said output (5).

2. A regenerator according to claim 1, in which the data division stage (2) includes a plurality of optical gate means (9,10) each arranged to receive the incoming data stream at a respective data input and to receive at a respective control input an optical clock stream at the frequency of the bit rate of the further signals, and delay means arranged to impose a different respective delay (11) on the said optical clock stream relative to the incoming data signal for each of the respective gate means.

3. A regenerator according to claims 1 or 2, in which the regenerator is arranged to regenerate a received bit-asynchronous optical packet, and in which each of the gate means (9,10) of the regeneration stage includes an array of optical gates (31-34), means for imposing different respective delays between the clock signal and the data signal at each of the gates making up the array and switch means for selecting an optical output from one of the gates in the array depending on the bit-level phase of the received optical packet.

4. A method of regenerating an optical data signal including the steps of:

(a) dividing an incoming optical data signal at a bit rate into a plurality of further data optical streams each having a lower bit rate than the bit rate of the incoming optical signal;

(b) gating under the control of the plurality of further data streams a clock signal at the frequency of the bit rate of the further signals or a multiple thereof; and

(c) interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the bit rate of the received optical data signal.

5. A method according to claim 4, in which the step of dividing the optical data signal includes applying the incoming optical data signal to a respective input of each of a plurality of gate means, applying to a respective control input of each of the plurality of gate means an optical clock stream at the frequency of the bit rate of the further signals or a multiple thereof, and imposing a different respective delay relative to the higher bit rate data signal on each of the said optical clock streams.

6. A method according to claim 4 or 5, in which the step of gating the clock signal includes applying each of the said data streams to an array of optical gates (31-34), imposing different respective delays between the clock signal and the data signal at each of the gates making up an array, and selecting an optical output from one of the plurality of gates in each array depending on the bit level phase of a received bit-asynchronous optical data signal.

7. A node for connection in an optical network and including a regenerator according to any one of claims 1 to 3.

8. An optical network including a regenerator according to any one of claims 1 to 3.

known as the gate window. The state of the gate is unchanged if a binary digit '0' occurs in the optical control signal. The state of the non-linear element then determines whether a given pulse in the optical clock train at the input to the gate is passed on to the output from the gate. In this way, the bit pattern in the input data stream is imposed on the optical clock train and output to form a regenerated optical data stream. However, while experiments reported in Kelly A E et al, Electronics Letters, (in press, July 1999) have shown that semiconductor-based all-optical regenerators can function at bit rates as high as 80Gbit/s it has been found that they are unable to perform satisfactorily at still higher bit rates, since then in general the bit period is very much less than the recovery time of the optical gate, so that the regenerated signals contain patterning effects which lead to bit errors.

According to a first aspect of the present invention, there is provided an optical regenerator comprising:

a data division stage arranged to receive an optical data stream at a higher bit rate and to divide the said optical data stream into a plurality of data streams at a lower bit rate; and

a regeneration stage including a plurality of optical gate means each arranged to receive a respective one of the plurality of data streams at its control input and to receive an optical clock stream at the frequency of the lower bit rate or a multiple thereof at another respective input, and the outputs of the said gate means being connected in common to an optical output of the regenerator and arranged to provide a bit-interleaved regenerated optical data stream at the said output.

The present invention provides an all-optical generator that is able to function at far higher bit rates than existing designs. For example, using current technologies, an all-optical regenerator functioning at 160Gbit/s can be constructed. The present inventors have realised that although the functioning of an optical regenerator is limited by the recovery time of the optical gate, the impact of that recovery time is different for a regular clock signal, as opposed to a signal comprising a random data sequence. Accordingly, a gate that may be able to function effectively as a regenerator for data signals only up to 80Gbit/s can nonetheless function as a demultiplexer for data signals at twice that bit rate. The regenerator of the present invention takes advantage of this difference to provide a system capable of operating at far higher bit rates. This is achieved by first dividing down the higher bit rate data

stream into a number of parallel data streams at a lower bit rate and then applying these different divided data streams at the lower bit rate as control signals to a number of gates, each of which is receiving a clock signal at the frequency of the lower bit rate or a multiple thereof at its input. Then when the outputs of the different gates are interleaved, the result is a regenerated data stream at the higher bit rate.

Preferably the data division stage comprises a plurality of gate means each arranged to receive the data stream at a respective driving input and a clock stream at the frequency of the lower bit rate at a respective control input and delay means arranged to impose a different respective delay on the clock signal at the frequency of the lower bit rate relative to the higher bit rate data signal for each of the respective gate means.

The all-optical regenerator may be arranged to function in a bit-synchronous network, in which case it may receive clock signals from local clock sources that are synchronised to a bit-level clock. In such a system, each of the gate means may comprise a single optical gate, for example using a TOAD (teraHertz optical asymmetrical demultiplexer) structure.

Alternatively, the optical regenerator may be used in a network which functions asynchronously at the bit-level. In this case, the optical regenerator may incorporate the regenerator structures described and claimed in the present applicant's co-pending application PCT/GB99/01159 (A25594), the contents of which are incorporated herein by reference. In this case, each of the gate means in the regeneration stage may comprise an array of optical gates, and delay means arranged to impose a different respective delay in the clock stream relative to the data stream at each of the array of optical gates, and an optical switch connected to the outputs of all of the array of optical gates, and arranged selectively to output the optical data stream from one of the gates of the array. Alternatively, as described in our co-pending application, a single gate means may be used in conjunction with means to shift the phase of the incoming packet to match that of a local free-running optical clock source.

According to a second aspect of the present invention, there is provided a method of regenerating an optical data signal comprising:

(a) dividing an optical data signal at a higher bit rate into a plurality of data streams at a lower bit rate;

(b) gating under the control of the plurality of data streams a clock signal at the frequency of the lower bit rate or a multiple thereof; and

(c) interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the higher bit rate.

Systems embodying the present invention will now be described in further detail by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic of an optical regenerator embodying the invention;

Figure 2 is a diagram showing an optical gate suitable for use in the regenerator in Figure 1;

Figure 3 is a diagram showing a gate array for use in the regenerating stage of an asynchronous optical regenerator embodying the invention.

An optical regenerator comprises an optical data division stage 1 and an optical regeneration stage 2. An optical time division multiplexed (OTDM) data stream at a high bit rate, in this example 160Gbit/s, is received at an optical input 3 of the data division stage 1. Divided data streams at a lower bit rate, in this example 80Gbit/s are passed from optical outputs 4a, 4b of the data division stage 1 into the optical regeneration stage 2. The data streams are used to gate an optical clock signal at the frequency of the lower bit rate or a multiple thereof, in this example 80 GHz, so as to produce at the optical output 5 of the regeneration stage 2 a regenerated high bit-rate optical data stream.

In a regenerator for use with a synchronous data stream, the data division and regeneration stages require in total 2n optical gates where n is the ratio between the bit rate of the optical data stream and the lower bit rate of the divided data streams input to the regeneration stage 2. In the present example, n=2 and there are two optical gates in the division stage 1 and a further two optical gates in the regeneration stage 2. As shown in Figure 1, each of the two gates in the division stage 1 is connected in common to the optical input 3 and is driven by the 160Gbit/s optical pulse stream. An optical clock signal at the lower bit rate of 80GHz is applied to each of the optical gates 6, 7. An optical delay 8 is included between the optical feeds to the gates 6, 7. The magnitude of the optical delay is said to be equal to the

CLAIMS

1. An optical regenerator comprising:

(a) a data division stage arranged to receive an optical data stream at a higher bit rate and to divide the said optical data stream into a plurality of data streams at a lower bit rate; and

(b) a regeneration stage, including a plurality of optical gate means each arranged to receive a respective one of the plurality of data streams at its control input and to receive an optical clock stream at the frequency of the lower bit rate or a multiple thereof at another input, and the outputs of the said gate means being connected in common to an optical output of the regenerator and arranged to provide a bit-interleaved regenerated optical data stream at the said output.

2. A regenerator according to Claim 1, in which the data division stage comprises a plurality of gate means each arranged to receive the data stream at a respective input and to receive an optical clock stream at the frequency of the lower bit rate at a respective control input, and delay means arranged to impose a different respective delay on the said optical clock stream relative to the higher bit rate data signal for each of the respective gate means.

3. A regenerator according to claims 1 or 2, in which the regenerator is arranged to regenerate a bit-asynchronous optical packet, and in which each of the gate means of the regeneration stage comprises an array of optical gates, means for imposing different respective delays between the clock signal and the data signal at each of the gates making up the array and switch means for selecting an optical output from one of the gates in the array depending on the bit-level phase of the received optical packet.

4. A method of regenerating an optical data signal comprising:

(a) dividing an optical data signal at a higher bit rate into a plurality of data streams at a lower bit rate;

(b) gating under the control of the plurality of data streams a clock signal at the frequency of the lower bit rate or a multiple thereof; and

(c) interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the higher bit rate.

5. A method according to claim 4, in which the step of dividing the optical data signal includes applying the optical data signal to a respective input of each of a plurality of gate means, applying to a respective control input of each of the plurality of gate means an optical clock stream at the frequency of the lower bit rate or a multiple thereof, and imposing a different respective delay relative to the higher bit rate data signal on each of the said optical clock streams.

6. A method according to claim 4 or 5, in which the step of gating the clock signal includes applying each of the said data streams to an array of optical gates, imposing different respective delays between the clock signal and the data signal at each of the gates making up an array, and selecting an optical output from one of the plurality of gates in each array depending on the bit-level phase of a received bit-asynchronous optical data signal.

7. A node for connection in an optical network and including a regenerator according to any one of claims 1 to 3.

8. An optical network including a regenerator according to any one of claims 1 to 3.

PATENT COOPERATION TREATY

PCT

INTERNATIONAL SEARCH REPORT

(PCT Article 18 and Rules 43 and 44)

Applicant's or agent's file reference A25819 WO	**FOR FURTHER ACTION** see Notification of Transmittal of International Search Report (Form PCT/ISA/220) as well as, where applicable, item 5 below.	
International application No. PCT/GB 00/ 02780	International filing date *(day/month/year)* 19/07/2000	(Earliest) Priority Date *(day/month/year)* 23/07/1999
Applicant BRITISH TELECOMMUNICATIONS		

This International Search Report has been prepared by this International Searching Authority and is transmitted to the applicant according to Article 18. A copy is being transmitted to the International Bureau.

This International Search Report consists of a total of 3 sheets.

[X] It is also accompanied by a copy of each prior art document cited in this report.

1. **Basis of the report**

   a. With regard to the **language**, the international search was carried out on the basis of the international application in the language in which it was filed, unless otherwise indicated under this item.

      [ ] the international search was carried out on the basis of a translation of the international application furnished to this Authority (Rule 23.1(b)).

   b. With regard to any **nucleotide and/or amino acid sequence** disclosed in the international application, the international search was carried out on the basis of the sequence listing :

      [ ] contained in the international application in written form.
      [ ] filed together with the international application in computer readable form.
      [ ] furnished subsequently to this Authority in written form.
      [ ] furnished subsequently to this Authority in computer readble form.
      [ ] the statement that the subsequently furnished written sequence listing does not go beyond the disclosure in the international application as filed has been furnished.
      [ ] the statement that the information recorded in computer readable form is identical to the written sequence listing has been furnished

2. [ ] **Certain claims were found unsearchable** (See Box I).

3. [ ] **Unity of invention is lacking** (see Box II).

4. With regard to the **title,**

   [ ] the text is approved as submitted by the applicant.
   [X] the text has been established by this Authority to read as follows:

   OPTICAL REGENERATOR FOR HIGH BIT-RATE OTDM SIGNALS

5. With regard to the **abstract,**

   [X] the text is approved as submitted by the applicant.
   [ ] the text has been established, according to Rule 38.2(b), by this Authority as it appears in Box III. The applicant may, within one month from the date of mailing of this international search report, submit comments to this Authority.

6. The figure of the **drawings** to be published with the abstract is Figure No. 1

   [X] as suggested by the applicant.
   [ ] because the applicant failed to suggest a figure.
   [ ] because this figure better characterizes the invention.
   [ ] None of the figures.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/02780

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H04B10/17 H04J14/08 H04L7/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H04L H04J H04B G02F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	BIGO S ET AL: "DUAL-CONTROL NONLINEAR-OPTICAL LOOP MIRRORS FOR ALL-OPTICAL SOLITON SYNCHRONOUS MODULATION" OPTICS LETTERS,US,OPTICAL SOCIETY OF AMERICA, WASHINGTON, vol. 21, no. 18, page 1463-1465 XP000630829 ISSN: 0146-9592 page 1463, left-hand column, line 39 -right-hand column, line 3 page 1464, left-hand column, line 29 - line 36 figures 1,2 ---	1,2,4

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
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Date of the actual completion of the international search	Date of mailing of the international search report
20 September 2000	27/09/2000

Name and mailing address of the ISA	Authorized officer
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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
A	COTTER D ET AL: "ASYNCHRONOUS DIGITAL OPTICAL REGENERATION AND NETWORKS" JOURNAL OF LIGHTWAVE TECHNOLOGY,US,IEEE. NEW YORK, vol. 16, no. 12, page 2068-2080 XP000833954 ISSN: 0733-8724 page 2071, left-hand column, line 45 -right-hand column, line 23 page 2072, left-hand column, line 9 - line 26 page 2077, right-hand column, line 21 -page 2078, left-hand column, line 19 figures 4,5,15 ---	1,3-5
A	GUNNING P ET AL: "10 Gbit/s asynchronous digital optical regenerator" OPTICAL FIBER COMMUNICATION CONFERENCE OFC/IOOC '99, TECHNICAL DIGEST, vol. 1, 21 - 26 February 1999, pages 134-136, XP002127915 page 134, right-hand column, line 14 - line 39 ---	1,3,4
A	US 5 798 852 A (SIMON JEAN-CLAUDE ET AL) 25 August 1998 (1998-08-25) column 9, line 1 - line 34; figures 2,3 -----	1

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/02780

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5798852 A	25-08-1998	FR 2735637 A	20-12-1996
		DE 19623634 A	19-12-1996
		GB 2302225 A,B	08-01-1997

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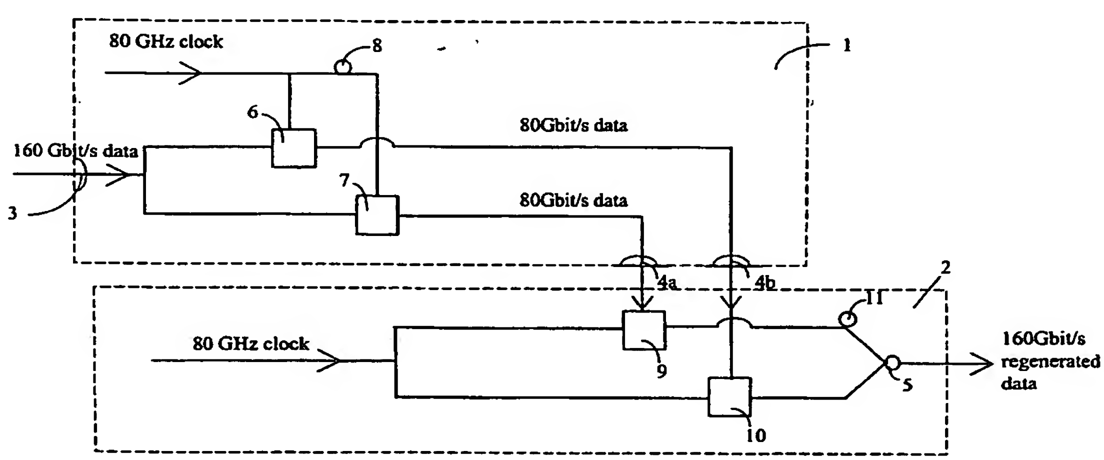
(54) Title: OPTICAL REGENERATOR FOR HIGH BIT-RATE OTDM SIGNALS



(57) Abstract: An optical regenerator suitable for use with optical signals has two stages. An incoming optical signal to be regenerated passes first through a data division stage. This divides the optical data stream into a number of data streams at a bit rate lower than the original optical signal. These data streams then pass to a regeneration stage. In the regeneration stage, there are a number of optical gates. Each gate receives one of the optical data streams at its control input. An optical clock stream at the lower or at a multiple thereof passes through the optical gates. The output of these optical gates are connected in common to the optical output of the regenerator and provide a bit-interleaved regenerated optical data stream at the output.

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OPTICAL REGENERATOR FOR HIGH BIT-RATE OTDM SIGNALS

The present invention relates to an optical regenerator suitable for use with optical time division multiplexed (OTDM) signals carried on an optical network. The signals may be, for example, optical packets or a circuit switched data stream.

In order to use fully the bandwidth available on optical communications networks, it is desirable to transmit time division multiplexed signals at a very high bit rate of tens or hundreds of Gbits per second. However, the very short duration pulses making up such signals soon suffer degradation in shape, timing and signal-to-noise ratio resulting, for example, from noise in optical amplifiers, dispersion in the optical transmission medium and/or from the effects of processing at nodes traversed by the packet. Therefore, if the extent of the optical network is not to be undesirably limited, it is necessary to use an optical regenerator to restore the timing and shape of the pulse train making up the optical signals. Ideally, the regenerator will function as a "3R" regenerator, that is it will re-amplify, re-time and re-shape the pulses. Examples of suitable optical regenerators are described in Lucek J and Smith K, Optics Letters, 18, 1226-28 (1993), and in Phillips I D, Ellis A D, Thiele H J, Manning R J and Kelly A E, Electronics Letters, 34, 2340-2342 (1998). The use of such techniques makes it possible to maintain the integrity of the optical data signals as they pass through a very large number of nodes. For example, Thiele H J, Ellis A D and Phillips I D, Electronics Letters, 35, 230-231 (1999) describe cascaded 40 Gbit/s 3R data regeneration in a recirculating loop. With a regenerator spacing of 100 km, the error-free transmission distance in the loop is extended by an order of magnitude, from 200 km to greater than 2000 km. Regenerators made from semiconductor non-linear optical devices, rather than fibre non-linear optical devices, are preferred because they are compact, stable, easily integrated, and operate at relatively low pulse energy.

Typically, an optical regenerator comprises an optical gate having a first optical input that receives an optical clock signal at the data line rate, and a second optical input, the control input that receives the data signal that is to be regenerated. Typically the gate, which includes a non-linear optical element, changes to a transmissive state when a binary digit '1' occurs in the optical control signal that is applied, and reverts to the original non-transmissive state after a certain fixed time

known as the gate window. The state of the gate is unchanged if a binary digit '0' occurs in the optical control signal. The state of the non-linear element then determines whether a given pulse in the optical clock train at the input to the gate is passed on to the output from the gate. In this way, the bit pattern in the input data stream is imposed on the optical clock train and output to form a regenerated optical data stream. However, while experiments reported in Kelly A E et al, Electronics Letters, (in press, July 1999) have shown that semiconductor-based all-optical regenerators can function at bit rates as high as 80Gbit/s it has been found that they are unable to perform satisfactorily at still higher bit rates, since then in general the bit period is very much less than the recovery time of the optical gate, so that the regenerated signals contain patterning effects which lead to bit errors.

According to a first aspect of the present invention, there is provided an optical regenerator comprising:

a data division stage arranged to receive an optical data stream at a higher bit rate and to divide the said optical data stream into a plurality of data streams at a lower bit rate; and

a regeneration stage including a plurality of optical gate means each arranged to receive a respective one of the plurality of data streams at its control input and to receive an optical clock stream at the frequency of the lower bit rate or a multiple thereof at another respective input, and the outputs of the said gate means being connected in common to an optical output of the regenerator and arranged to provide a bit-interleaved regenerated optical data stream at the said output.

The present invention provides an all-optical generator that is able to function at far higher bit rates than existing designs. For example, using current technologies, an all-optical regenerator functioning at 160Gbit/s can be constructed. The present inventors have realised that although the functioning of an optical regenerator is limited by the recovery time of the optical gate, the impact of that recovery time is different for a regular clock signal, as opposed to a signal comprising a random data sequence. Accordingly, a gate that may be able to function effectively as a regenerator for data signals only up to 80Gbit/s can nonetheless function as a demultiplexer for data signals at twice that bit rate. The regenerator of the present invention takes advantage of this difference to provide a system capable of operating at far higher bit rates. This is achieved by first dividing down the higher bit rate data

stream into a number of parallel data streams at a lower bit rate and then applying these different divided data streams at the lower bit rate as control signals to a number of gates, each of which is receiving a clock signal at the frequency of the lower bit rate or a multiple thereof at its input. Then when the outputs of the different gates are interleaved, the result is a regenerated data stream at the higher bit rate.

Preferably the data division stage comprises a plurality of gate means each arranged to receive the data stream at a respective driving input and a clock stream at the frequency of the lower bit rate at a respective control input and delay means arranged to impose a different respective delay on the clock signal at the frequency of the lower bit rate relative to the higher bit rate data signal for each of the respective gate means.

The all-optical regenerator may be arranged to function in a bit-synchronous network, in which case it may receive clock signals from local clock sources that are synchronised to a bit-level clock. In such a system, each of the gate means may comprise a single optical gate, for example using a TOAD (teraHertz optical asymmetrical demultiplexer) structure.

Alternatively, the optical regenerator may be used in a network which functions asynchronously at the bit-level. In this case, the optical regenerator may incorporate the regenerator structures described and claimed in the present applicant's co-pending application PCT/GB99/01159 (A25594), the contents of which are incorporated herein by reference. In this case, each of the gate means in the regeneration stage may comprise an array of optical gates, and delay means arranged to impose a different respective delay in the clock stream relative to the data stream at each of the array of optical gates, and an optical switch connected to the outputs of all of the array of optical gates, and arranged selectively to output the optical data stream from one of the gates of the array. Alternatively, as described in our co-pending application, a single gate means may be used in conjunction with means to shift the phase of the incoming packet to match that of a local free-running optical clock source.

According to a second aspect of the present invention, there is provided a method of regenerating an optical data signal comprising:

(a) dividing an optical data signal at a higher bit rate into a plurality of data streams at a lower bit rate;

(b) gating under the control of the plurality of data streams a clock signal at the frequency of the lower bit rate or a multiple thereof; and

(c) interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the higher bit rate.

Systems embodying the present invention will now be described in further detail by way of example only, with reference to the accompanying drawings in which:

Figure 1 is a schematic of an optical regenerator embodying the invention;

Figure 2 is a diagram showing an optical gate suitable for use in the regenerator in Figure 1;

Figure 3 is a diagram showing a gate array for use in the regenerating stage of an asynchronous optical regenerator embodying the invention.

An optical regenerator comprises an optical data division stage 1 and an optical regeneration stage 2. An optical time division multiplexed (OTDM) data stream at a high bit rate, in this example 160Gbit/s, is received at an optical input 3 of the data division stage 1. Divided data streams at a lower bit rate, in this example 80Gbit/s are passed from optical outputs 4a, 4b of the data division stage 1 into the optical regeneration stage 2. The data streams are used to gate an optical clock signal at the frequency of the lower bit rate or a multiple thereof, in this example 80 GHz, so as to produce at the optical output 5 of the regeneration stage 2 a regenerated high bit-rate optical data stream.

In a regenerator for use with a synchronous data stream, the data division and regeneration stages require in total 2n optical gates where n is the ratio between the bit rate of the optical data stream and the lower bit rate of the divided data streams input to the regeneration stage 2. In the present example, n = 2 and there are two optical gates in the division stage 1 and a further two optical gates in the regeneration stage 2. As shown in Figure 1, each of the two gates in the division stage 1 is connected in common to the optical input 3 and is driven by the 160Gbit/s optical pulse stream. An optical clock signal at the lower bit rate of 80GHz is applied to each of the optical gates 6, 7. An optical delay 8 is included between the optical feeds to the gates 6, 7. The magnitude of the optical delay is said to be equal to the

separation between successive bits in the optical data stream at the input 3. As a result, the two optical gates 6, 7 each pass every other bit of the input data stream with, for example, gate 6 passing the optical pulses in bit positions 0, 2, 4 ... and the other gate 7 passing the optical pulses in bit positions 1, 3, 5... The resulting divided data streams at the lower bit rate are passed to the optical outputs 4a, 4b of the data division stage 1. In the regeneration stage 2, a further pair of optical gates 9, 10 are driven by the 80GHz optical clock signal. A respective one of the divided data signals is applied as a control signal to each of the gates 9, 10. An optical delay 11 is included in the output from one of the gates 9, 10 and is arranged to impose a relative delay between the outputs of the gates 9, 10 that is complementary to the delay imposed in the data division stage 1. The outputs of the gates 9, 10 are then combined by an optical coupler 12. In this way, the two lower bit rate data streams are modulated onto the higher bit rate clock and interleaved to produce an output signal at 160Gbit/s that is regenerated in shape, amplitude and timing, that is it has undergone 3R regeneration.

Figure 2 shows one possible construction for an optical gate for use in the circuit of Figure 1. In this case, the gate uses a TOAD configuration. A fibre loop mirror 21 includes a non-linear element 22 which may be, for example, an optical semiconductor amplifier. The non-linear element 22 is offset with respect to the centre of the loop mirror. The duration of the switching window is determined by the extent of the offset. A gating control signal is applied to the loop via an optical coupler 23.

Fibre loop mirrors in which the fibre itself acts as the non-linear element are described, for example, in Whittaker et al, Optical Letters, vol. 16, page 1840 (1991). The use of non-linearities in semiconductor optical amplifiers as an ultrafast gating device is described, for example, by Kang et al in the International Journal of High Speed Electronics and Systems, vol. 7, page 125 (1996). As an alternative to the use of a semiconductor optical amplifier in a loop configuration as shown in Figure 2, an optical gate may use a pair of amplifiers in a Mach-Zehnder interferometer configuration. Another ultrafast optical gate is the ultrafast non-linear interferometer switch described by Hall and Rauschenbach (Paper BD5, Proceedings of Conference on Optical Fibre Communications (OFC '98) Optical Society of America, February 1998). It is characteristic of all these devices, that they suffer

significant speed limitations as a result of the recovery time of the non-linear element when the gate is driven by an irregular data signal. However, they can function at considerably higher data rates when driven by a regular clock signal.

To generate the clock signals at and the frequency of the lower bit rate, a clock recovery circuit may be used to derive a clock signal in synchronism with the incoming data bits and this clock signal may be used to synchronise a local pulse source running at 80GHz. For example, the clock recovery circuit may comprise a passive pulse replication network that replicates a marker pulse to produce a regular pulse pattern.

In an alternative embodiment, the optical regenerator is arranged to handle incoming optical packets that are asynchronous at the bit-level. In this case, each of the single optical gates 9, 10 in the regenerative stage of Figure 1 is replaced by an array of gates. One such array is shown in Figure 3. The array comprises four optical gates 31, 32, 33, 34. Each of the gates is driven by the 160Gbit/s data stream. Different relative delays of a fraction of a bit period are included in the input paths for the driving signals. This delay has a value of 0 for the input to the first optical gate 31 $\pi/4$ for the second optical gate 32, $\pi/2$ for the third optical gate 33, and $3\pi/4$ for the final optical gate 34. The outputs from the four optical gates are passed to a 4:1 optical switch which selects the data stream from one of the gates to be passed to the respective optical output 4a, 4b. The appropriately synchronised output may be selected, for example, by tapping off a fraction of the output from the switch C and measuring, for example using a photo detector, the optical energy in the data signal each of the different gates is selected. When the phase error between the clock signal and driving data signal is minimised, then the corresponding gate output will give a peak in the energy function. Electronic control logic may be used to generate an electronic control signal for the 4:1 switch. The lower switching rates of electronic control logic is not a limiting factor, since the selection of an optical output from the gate array only needs to be repeated at the packet rate. In such systems handling bit asynchronous optical packets, the optical clock signals may be derived from free-running optical pulse sources. A suitable source comprises an electronic microwave oscillator driving an electrically synchronised laser, such as a gain-switched laser or an actively mode-locked laser. Alternative, a continuously free-running optical pulse source such as a passively mode-locked laser may be used.

In general, an asynchronous optical regenerator will require 5 n gates, where n is the ratio between the higher bit rate and the lower bit rate.

Figure 4 shows, by way of example, an optical network in which a node includes a bit-asynchronous regenerator embodying the invention. Packets arrive at the node referenced B from a number of sources, each of which have independent, uncorrelated clocks. . By suitable adjustment of the transmitted power at the source, the power levels in any optical amplifiers used in the link, and also the power levels at any synchronous regenerators used in the link, the bits in the packets arriving at the input of a routing node may conveniently have an intensity at an appropriately-defined standard 'digital' level (e.g. of the correct intensity to perform complete switching in the optical gate or gates used in the bit-asynchronous packet regenerator AR in the switching node). The inputs to the switching nodes will, in general, be bit-asynchronous. Each input to a routing node may pass through a bit-asynchronous packet regenerator AR, constructed as described above. As is shown schematically in Figure 4 a node, such as that referenced node B, may combine an add/drop function for local traffic as well as regenerating packets for onward transmission.

CLAIMS

1. An optical regenerator comprising:

(a) a data division stage arranged to receive an optical data stream at a higher bit rate and to divide the said optical data stream into a plurality of data streams at a lower bit rate; and

(b) a regeneration stage, including a plurality of optical gate means each arranged to receive a respective one of the plurality of data streams at its control input and to receive an optical clock stream at the frequency of the lower bit rate or a multiple thereof at another input, and the outputs of the said gate means being connected in common to an optical output of the regenerator and arranged to provide a bit-interleaved regenerated optical data stream at the said output.

2. A regenerator according to Claim 1, in which the data division stage comprises a plurality of gate means each arranged to receive the data stream at a respective input and to receive an optical clock stream at the frequency of the lower bit rate at a respective control input, and delay means arranged to impose a different respective delay on the said optical clock stream relative to the higher bit rate data signal for each of the respective gate means.

3. A regenerator according to claims 1 or 2, in which the regenerator is arranged to regenerate a bit-asynchronous optical packet, and in which each of the gate means of the regeneration stage comprises an array of optical gates, means for imposing different respective delays between the clock signal and the data signal at each of the gates making up the array and switch means for selecting an optical output from one of the gates in the array depending on the bit-level phase of the received optical packet.

4. A method of regenerating an optical data signal comprising:

(a) dividing an optical data signal at a higher bit rate into a plurality of data streams at a lower bit rate;

(b) gating under the control of the plurality of data streams a clock signal at the frequency of the lower bit rate or a multiple thereof; and

(c) interleaving the optical signals produced by step (b) thereby creating a re-generated optical signal at the higher bit rate.

5. A method according to claim 4, in which the step of dividing the optical data signal includes applying the optical data signal to a respective input of each of a plurality of gate means, applying to a respective control input of each of the plurality of gate means an optical clock stream at the frequency of the lower bit rate or a multiple thereof, and imposing a different respective delay relative to the higher bit rate data signal on each of the said optical clock streams.

6. A method according to claim 4 or 5, in which the step of gating the clock signal includes applying each of the said data streams to an array of optical gates, imposing different respective delays between the clock signal and the data signal at each of the gates making up an array, and selecting an optical output from one of the plurality of gates in each array depending on the bit-level phase of a received bit-asynchronous optical data signal.

7. A node for connection in an optical network and including a regenerator according to any one of claims 1 to 3.

8. An optical network including a regenerator according to any one of claims 1 to 3.

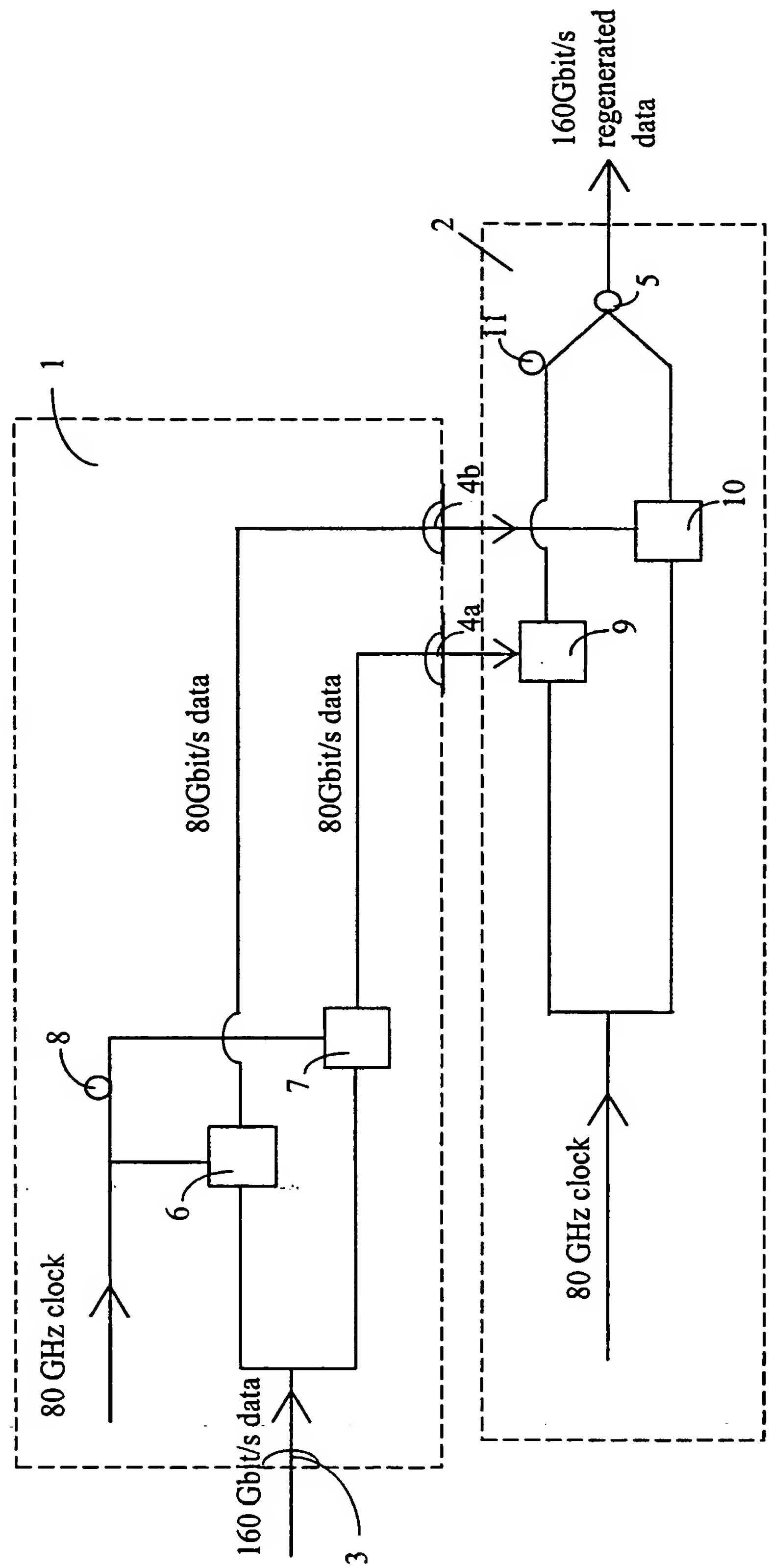

160Gbit/s regenerated data
2
5
11
1
4b
10
4a
9
80Gbit/s data
80Gbit/s data
8
7
6
80 GHz clock
80 GHz clock
160 Gbit/s data
3

Figure 1

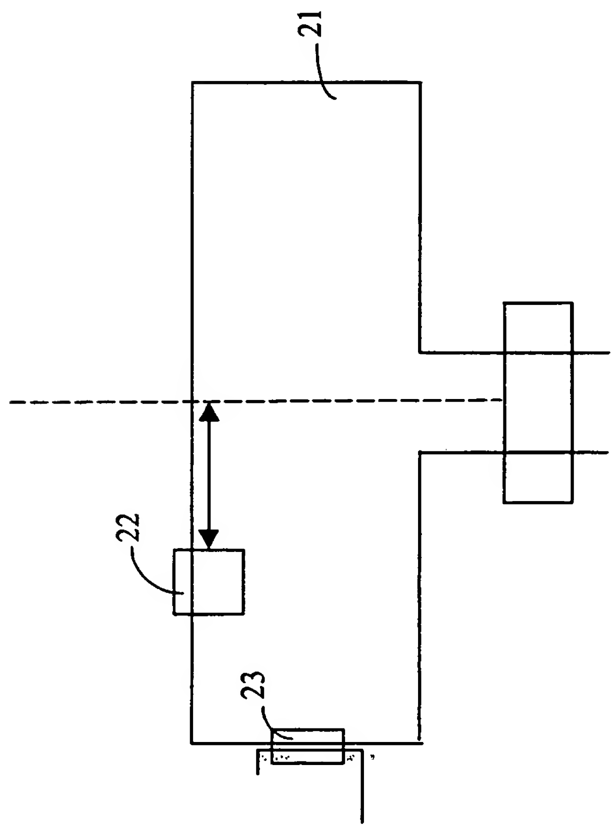


Figure 2

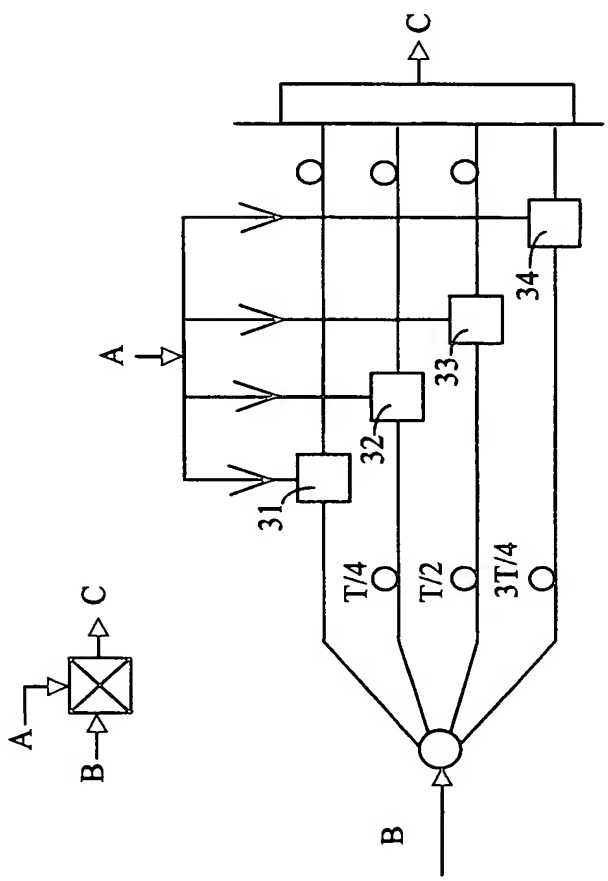
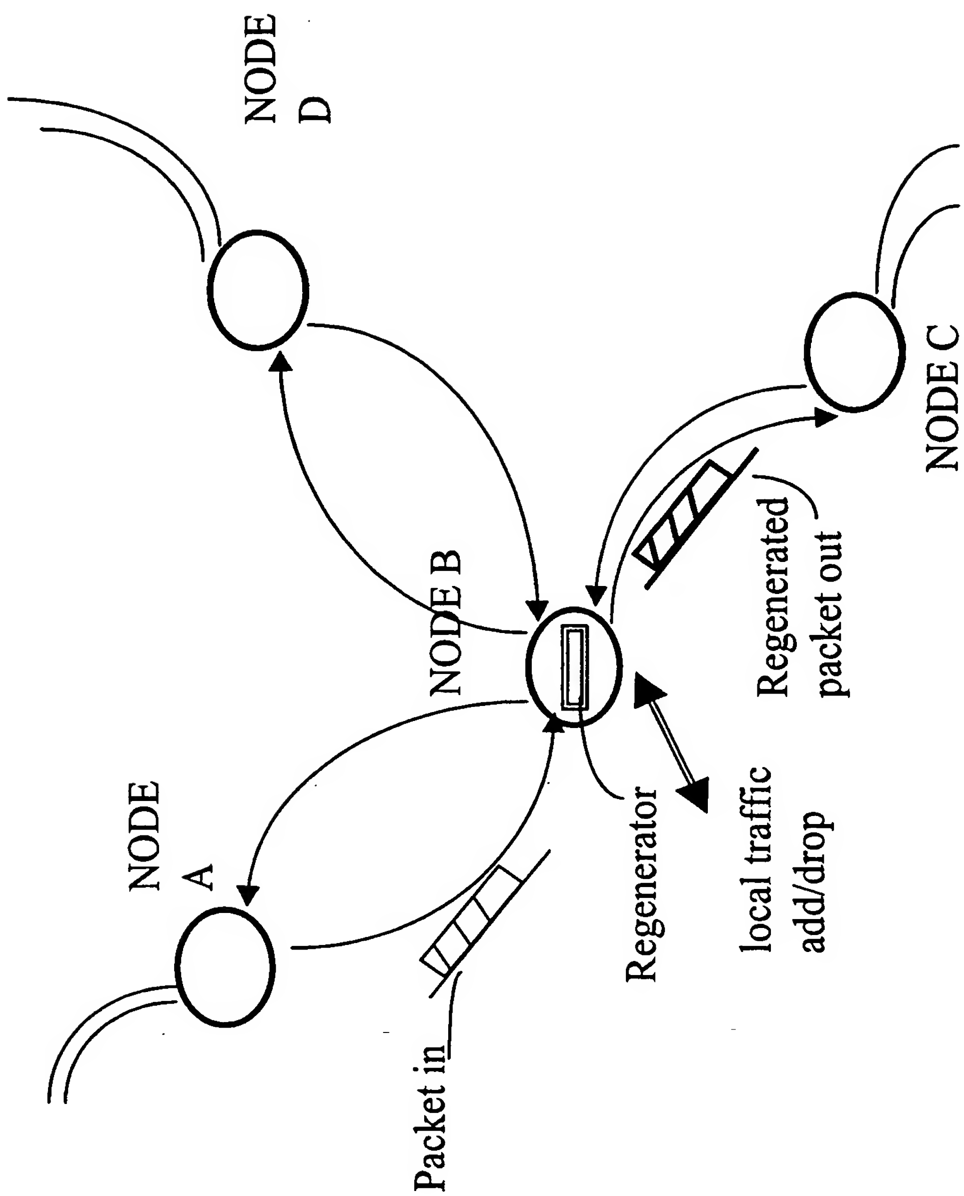


Figure 3

Figure 4


NODE D
NODE C
NODE B
NODE A
Regenerated packet out
Regenerator
local traffic add/drop
Packet in